METEOROLOGICAL ASPECTS OF OCEANOGRAPHY.

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[Dated: Oceanografiska Institutionen, University of Gothenburg, May, 1916. Received June 12, 1916.]

For many centuries oceanographical investigations were carried on for purely practical, viz, nautical purposes only. Practically all we know of the bathymetrical features of the shallower parts of the ocean is based on soundings taken for practical reasons. The same applies to our knowledge of tidal phenomena which has culminated in modern tidal predictions, a field where science applied to practical purposes has scored one of its most brilliant successes.

The vast systems of currents which traverse the surface of the oceans have become known to us mainly through unnumbered observations by ocean-going merchant vessels; observations which were for the first time thoroughly investigated and made useful to man by the classical work of the distinguished American scientist, Maury, the father of oceanography.

During the last 20 or 30 years a new practical reason for marine research has arisen, namely, the rapidly increasing importance of the fishing industry. Since the introduction of steam trawlers the high-sea fisheries in various important areas have become so intensified that disquieting results of overfishing are plainly visible. The necessity of safeguarding against this evil was one of the main motives which led to the establishment of an international organization for the study of the sea which, for more than 12 years, had vigorously pursued systematic investigations of the propagation, growth, and migrations of the most valuable food fishes as well as their dependence on the variable physical and chemical properties of the sea water. A definite proposal for international legislative measures against excessive fishing of immature fishes had already been put forward by this organization when the outbreak of the present war brought its work to a temporary standstill.

Besides these two practical motives for systematic investigations of the ocean there is a third reason for increasing and perfecting our present knowledge of the sea, a reason which will no doubt become more generally acknowledged in the near future. I refer to the all-important influence which the ocean exercises over the climate and the weather of the surrounding continents. The object of the present paper is to give a brief survey of the most prominent ways in which this influence becomes manifest.

INFLUENCE OF THE OCEAN ON AIR TEMPERATURES.

From a thermal point of view the function of the ocean is twofold. It accumulates solar heat and redistributes it more evenly both in *time* and in *space*. Its power to do so is derived mainly from two physical properties of water, viz, its large heat capacity (1 cubic meter of water on cooling 1° C. will raise the temperature of 3,000 cubic meters of air by the same amount) and its mobility. The mobility of the water in the vertical dimension assists in carrying out the first of the two functions before mentioned, while its mobility in the horizontal plane enables the ocean to exert its second thermo-regulating function, i. e., by means of its large warm and cold surface currents.

As regards the capacity of the ocean to distribute heat of solar origin more evenly in time—to act as a kind of "savings bank" for solar energy, receiving deposits in seasons of excessive insolation and paying them back in seasons of want—we can get a faint idea of the state of things which would prevail were the earth devoid of its oceans by comparing the climate of central Eurasia with that of Scandinavia or the British Isles. The following figures, which give the number of heat units (kg.-cal.) passing in and out through 1 square meter of different surfaces per annum, are also very illuminating.

Number of heat units (kg.-cal.) passing in and out through 1 square meter of different surfaces annually.

	Kg.-cal.
Sandy soil in a forest	13,000
Sandy soil under grass	18,500
A fresh-water lake (down to 24 meters)	280,000
Southern Baltic (down to 55 meters)	520,000

Not less important is the second function of the ocean, viz, that of distributing its store of heat (accumulated chiefly in the Tropics) more evenly over the surface of the globe. The profound manner in which the ocean modifies the temperature conditions of our planet is perhaps best demonstrated by a chart showing the isotherms (yearly averages) of the North Atlantic surface waters, specially their abnormal trend to the north in its northeastern part where the sea's isotherm of 0°C. runs beyond the 80th parallel, i. e., some 10° farther than its average latitude for the Northern Hemisphere, and where the air temperature anomaly in January for certain areas off the Norwegian coast shows positive values of *not less than* +27°C. To return to our metaphor: The savings bank for solar heat which we call the ocean has a very extensive "foreign exchange."

So far these facts are of course generally acknowledged. Important as the temperature-regulating functions of the ocean undoubtedly are, they would afford but little actual interest were they always, from year to year, exercised in exactly the same manner and with unvarying intensity. However, there is ample evidence to show that this is not the case. Or, metaphorically, the annual "dividends" paid by this bank to its "shareholders," i. e., the continents round its borders, are emitted on a variable scale.

There are years when the heat supply runs down to famine values, and other years of lavish abundance. Exact proofs of this fact were first produced 20 years ago in a paper by Otto Pettersson,[1] which may be said to open new perspectives on the relationship between oceanography and meteorology. By means of curves extending over many years it was shown that the surface temperatures of the Atlantic off the coast of Norway in winter (monthly averages for January and February) vary considerably from year to year, and that these variations are reflected on a magnified scale in perfectly parallel fluctuations of the air temperature over central Sweden. Further, it was shown that the same parallelism is revealed in various important phenomena in nature, such as the disappearance of the snow cover, the development of vegetation (flowering of certain spring herbs), and also in the thawing of the soil (marked by the commencement of plowing).

A curve (fig. 1) showing the latter relationship is reproduced here from Pettersson's paper.[1] To put the matter more explicitly, the date on which agricultural spring work can begin, which is of very great importance for the subsequent development of the crop, is determined by oceanographical conditions *which prevail two to three months earlier*.

[1] *Pettersson, Otto.* Ueber die Beziehungen zwischen hydrographischen und meteorologischen Phänomenen. Meteorolog. Ztschr., Aug., 1896, 13: 285 and 316, fig. 14.

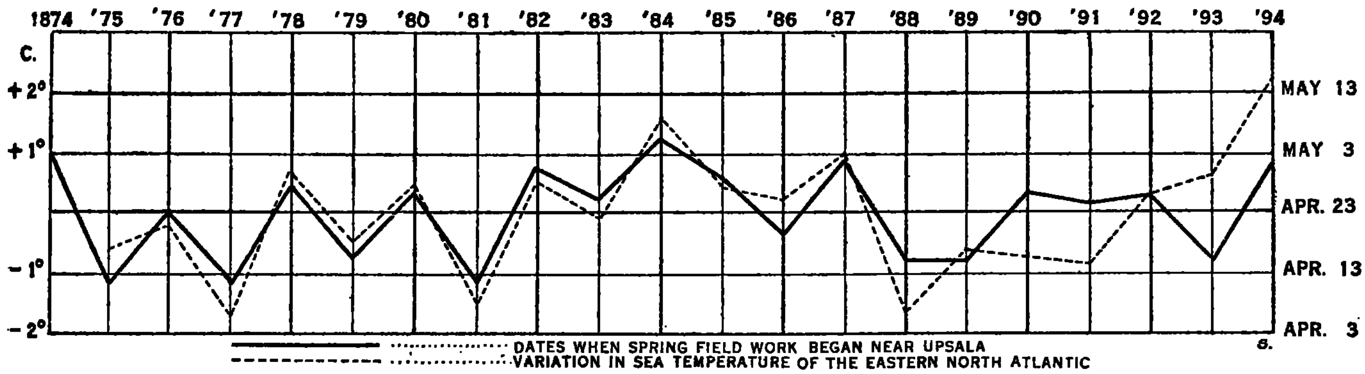

FIG. 1.—Curves comparing fluctuations in dates of beginning of spring field work near Upsala, with variations in the temperature of the Atlantic off coast of Norway.

A number of other investigators, such as Meinardus and Hildebrandsson, have taken up work along the lines pointed out by Otto Pettersson and have clearly proved the surprising extent to which dominant meteorological features of Europe are governed by the prevailing state of the surface sheet of the North Atlantic. So far, however, hardly any practical benefit has been derived from these discoveries.

The efforts of modern meteorologists seem to be almost exclusively directed toward the attainment of *short-range* forecasts, viz, the prediction of the probable weather which will prevail a couple of days later. The greatest living authority on dynamical meteorology, V. Bjerknes, is reported to have said that the problem of foretelling the weather three days in advance from a sufficiently detailed knowledge of the meteorological elements over a certain area is completely solved. Only the intricate calculations required for a solution in the individual case will keep a staff of trained assistants busy for several weeks!

The importance of successful short-range forecasts of course must not be underestimated. Apart from its value for other open-air activities, it may become eminently useful to agriculture, specially at harvest time; while their value for the fishing and shipping industries, in the shape of storm warnings, has been established beyond dispute. This is particularly the case in Sweden where these predictions have proved eminently successful owing to the excellent work of Dr. Nils Ekholm.

However, it would appear that still greater practical benefit might be reaped from long-range forecasts defining the average character of a coming season, such predictions as Pettersson proclaimed to be possible in his paper before mentioned. Growing crops worth millions of dollars may be more or less ruined by a cold spring, a hot and dry summer, or a wet autumn, and an early warning of such prospects would have a value which can hardly be overestimated. Besides trying to predict the extremely variable state of the fickle atmosphere one should give more attention to the *conservative element* in meteorology, viz, the surface sheet of the ocean where changes may be observed months before their effect on our weather becomes manifest.

Unfortunately our present lamentable lack of knowledge of this marine element makes it practically impossible now to give similar forecasts of any value. It is therefore a most welcome symptom that the meteorological services of several countries have of late started to issue monthly charts giving the actual state of the surface of the North Atlantic (or rather of those parts which lie along the principal ship routes) and also to work up portions of the immense material contained in the log books of the ocean-going merchant vessels. Pioneer work of this kind has already been completed by Nansen and Helland-Hansen whose results, as yet unpublished, prove that unmistakable changes in the surface temperature of the North Atlantic occur from year to year and that these changes *run parallel over vast areas,* if not over the whole ocean.

Finally the International Council for the Study of the Sea, at Copenhagen, are employing the leisure due to the temporary interruption of their regular research by the war, by taking up this kind of work on a still broader scale, viz, the average hydrographical conditions of certain representative areas for the period 1900–1913, as well as the departures from these values for each month of the same time. In this work the excellent observations extending over some 40 years compiled by the Danish Meteorological Office have proved particularly valuable.

It is earnestly to be hoped that when the end of the present state of war makes a return to sane occupations possible, the International Council may be able to extend its carefully worked-out methods and experience of organized scientific work on practical problems, to the larger field of the North Atlantic Ocean.

With regard to long-range forecasts of the kind indicated in this paper the most important part of the whole North Atlantic are the coastal waters of the eastern United States, specially the Strait of Florida. By means of a few recording current meters—to be described in a succeeding paper—combined with thermographs a close watch might be kept at comparatively low cost over this pulse of the Gulf Stream. A sensible departure from the average value of the vast amount of stored heat carried through this strait (some 10^{12} heat units per hour if the water were to be cooled only to +10° C.) might have profound effects on the weather of the following months both on the European and the North American continents. Similar observations off the coasts of Formosa would no doubt be of corresponding value for predicting the weather of Japan.

INFLUENCE OF THE OCEAN ON ATMOSPHERIC CIRCULATION.

It is quite easy to prove that if the temperature were and remained uniform all over the surface of our planet there would be no atmospheric circulation whatever; a perpetual dead calm would reign supreme. On the other hand, it is also evident that the more rapidly the temperature varies along the earth's surface at a certain locality the more intense, in general, will be the atmospheric disturbances set up there. Therefore, wherever great contrasts of temperature prevail within short distances, the locality will be distinguished by the large number of atmospheric disturbances which either originate there or are stimulated by it.

Now the ocean, in discharging the second of its temperature-regulating functions, viz, redistributing solar heat in space, is responsible for bringing together great contrasts of temperature. This is specially the case where a warm current collides with a cold one, or where it runs along mountainous ridges at the edge of a winter-cold continent. A striking example of the first type is the coast of the northeastern United States and Newfoundland where the ice-cold Labrador Current runs right into the Gulf Stream drift current and where the isotherms run more crowded together than in any other part of the world.[2] Also the locality in question has of old been popularly known as the "storm breeder," and it really seems to be a junction of the first order for the tracks of transcontinental cyclones coming from the west. If the intensity of the temperature contrasts for this area, i. e., the strength of the temperature gradient along the surface, were known for a number of years it might show a pronounced parallelism with simultaneous changes in the storm-frequency curve for the surrounding parts of the ocean.[3]

An example of the second type is afforded by the region off the coast of northwestern Scandinavia, where in January the aforesaid temperature anomaly of +27° C. prevails. The effect on the atmospheric circulation is also most striking, as has been proved through recent studies by J. W. Sandström, the eminent Swedish meteorologist. Having set himself the task of discovering by what kind of atmospheric mechanism the Norwegian Sea does exert over the Scandinavian climate that influence discovered by O. Pettersson, Sandström[4] made prolonged explorations in the Scandinavian Alps during midwinter and at considerable personal risks. He then found that the prevailing easterly winds, once they get over the highest ridges, will descend along the slopes to the sea, gaining impetus from the high density of the air (which is increased by the mass of snow it carries along with it) so that the air finally rushes like an ice-cold cataract at a terrific pace downward to the warm sea surface. There its temperature and amount of moisture are increased and some of the re-warmed air returns toward the European Continent as a westerly wind at a higher altitude. The boundary surface between the warm and moist upper current from the sea and the ice-cold lower current of opposite direction fluctuates considerably up and down, the west wind sometimes reaching as far down as to the mountain slopes, where the east wind is temporarily dammed up. However, when the east wind again breaks loose it descends with a redoubled violence. The wind velocity at the coast of Norway therefore sometimes increases from a gentle breeze to a gale of 30 meters per second (108 km. per hour) in the course of a few minutes, which may of course involve considerable loss of life and property to the fishing population. Storm warnings based on these discoveries by Sandström will shortly be issued by the Norwegian authorities.

The atmospheric circulation described here can be beautifully demonstrated in a trough with walls of plate glass such as I have used for hydrodynamical experiments (length 100 cm.; width 30 cm.; depth 22 cm.). The trough is divided transversely by a triangular block of rubber reaching halfway up its sides. One partition is filled with ice, and on the bottom of the other is placed a small metal box with hot water representing the Norwegian Sea. By exhaling some tobacco smoke into the trough, the circulation becomes plainly visible, and one sees a cataract of ice-cold air descending the slope of the rubber block and rising again abruptly over the hot metal, whereas an upper current immediately under the [glass?] cover is strongly drawn inward back over the ice. Conditions which are probably a rather less intense combination of both types prevail over the Japanese islands, which are also recognized as one of the stormiest regions of the world. Predictions of the storm frequency based on oceanographical observations appear, therefore, to be feasible for Japan also.

In his paper Pettersson also calls attention to the fact recognized already in 1879 by the Danish meteorologist, Hoffmeyer (Ztschr. d. Oesterr. Ges. f. Meteorol., 1878, **13**, and 1879, **14**), namely, that the distribution of the air pressure shows distinct effects of oceanic influences. Especially in the cold season is there a tendency for stationary barometric minima to develop and to remain stationary over water surfaces, as the latter are then in general considerably warmer than the surrounding land surfaces. A chart of the average isobars for the winter months plainly shows how closely these follow the outlines of the continents. These regions of relatively low pressure are of considerable importance in our latitudes on account of their evident close relation to the movements of the traveling barometric depressions, i. e., the cyclones. Maps of the principal storm tracks, such as those by van Bebber (see fig. 2), also show that regions like the North Sea with the Skagerrack, the southern Baltic—in a less degree even large lakes like Vännern (Sweden) and Ladoga (Russia) as long as they remain unfrozen—are touched by the most frequented storm tracks. A close and continuous study of the surface winter temperatures of these regions therefore ought to be useful for the drawing up also of short-range weather forecasts.

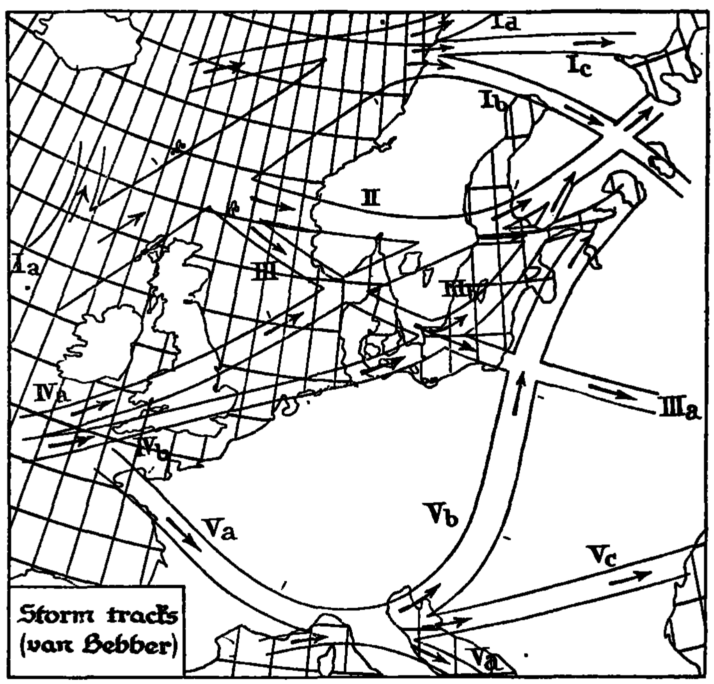

FIG. 2.—Storm tracks for northwestern Europe, after van Bebber.

The immense importance for our winter climate, of the large low-pressure region which prevails in winter over the warm ocean surface to the south of Iceland, was also pointed out by Hoffmeyer and has been the subject of

[2] This important area, which was studied already by the Challenger expedition, by Sigsbee, and others, has been investigated quite recently by the famous Norwegian fishery authority, Dr. John Hjort, at the request of the Canadian Government, with highly interesting results.

[3] The suggestions in this paragraph should be regarded as such. It remains to be proved that this junction of marine currents actually gives rise to cyclones. Most of those tracked originated somewhere far west of there.—C. A., jr.

[4] *See* his contributions to this REVIEW and to the Bulletin of the Mount Weather Observatory.—C. A., jr.

more recent remarkable studies by Teisserenc de Bort and his collaborator, Hildebrandsson.[5]

In fact the extent to which atmospheric circulation depends on oceanic conditions, when once fully recognized, will make a close cooperation between meteorologists and oceanographers a condition sine qua non for the formulation of successful weather forecasts.

THE INFLUENCE OF THE OCEAN ON RAINFALL.

From a theoretical point of view the prevailing conditions of the surface sheet of the ocean ought to have a decided influence on the amount of rain precipitated over the continents. However, so far no very definite proofs have been produced for the actual existence of the supposed relationship. The greatest part of the rain which falls over Europe is no doubt formed by evaporation from the surface of the North Atlantic. Now the rate of evaporation, which is a function of several variables, varies rapidly with temperature, a rise of 5 degrees from +10°C. to +15°C. corresponding to an increase in the vapor pressure of some 40 per cent. It would therefore appear very likely that an unusually low surface temperature over large parts of the North Atlantic may be followed by a reduced rainfall in a coming season. O. Pettersson[6] has proved that at times when an outburst of icebergs takes place in the South Indian Ocean the monsoon rains over India will, in general, be very scanty, which inevitably results in a more or less complete failure of the crops and subsequent famine among millions of human beings. The greatest outburst of icebergs in the South Indian Ocean occurred in 1895–1897, and 1896 was a year of exceptional drought in India; the crops there failed over several hundred thousand square miles and millions of the population were reduced to a state of famine.

Once we have full knowledge of the surface temperature (and the salinity) of the most representative parts of the North Atlantic Ocean, and can follow their variations from month to month, perhaps a kind of long-range forecast of the rainfall also may become feasible.

I have tried to point out that from the standpoint of the meteorologist a systematic and regular observation of the North Atlantic is a task which ought to be undertaken without delay and that it would have every prospect of gaining results of immense practical value to mankind.

In a succeeding paper I intend to give brief descriptions of some novel instruments and methods which make it possible to take isolated or continuous observations of various oceanographical elements with a minimum of labor and a high degree of accuracy.

PRECIPITATION OVER THE SOUTHEAST ROCKY MOUNTAIN SLOPE.[1]

By CLEVE HALLENBECK, Assistant Observer.

[Dated: Weather Bureau, Roswell, N. Mex., June 14, 1916.]

Nearly all of the general rains over the region embracing eastern New Mexico and the extreme western portion of Texas come with easterly winds. The greatest frequency of precipitation at the eastern border of this area is with southeast winds, gradually shifting to northeasterly by the time the Pecos Valley in New Mexico is reached. It can be said that in this region rains coming from any other directions than southeasterly and northeasterly are so infrequent as to be negligible.

It follows that any distribution of pressure giving rise to steady easterly winds over this region will be productive of precipitation. The most dependable condition is a low pressure area to the south; in general, south of the 35th parallel of latitude. Precipitation usually begins when the low has moved far enough eastward to bring the incurving winds from the Gulf over west Texas as easterly and over eastern New Mexico as northeasterly winds.

While these lows moving along the southern border nearly always produce precipitation, those that pass north of the 35th parallel seldom cause precipitation over this area. This is due to the topography of the Southwest. The Continental Divide, extending southward from Colorado, divides in northern New Mexico into two branches; the west branch extends southwestward nearly to the corner of the State, while the east branch extends southward, separating the Grande and the Pecos Valleys. The Divide has an elevation of 10,000 to 12,000 feet in the northern part of the State; through the central and southern portions of the State the two branches have about the same elevation of 8,000 feet. The eastern branch, however, extends down into Texas to the meeting of the Grande and Pecos, and thus becomes a controlling factor in the distribution of precipitation over this area. That part of Texas lying immediately east of this range is the dryest portion of the State.

Westerly winds over Arizona and New Mexico are "upslope" winds until they reach the western branch of the divide, then their direction averages about horizontal until they pass the crest of the eastern branch, after which they are "downslope" as long as their direction has an eastward component.

Taking now the case of a depression centered near the northern border of the State: over its western quadrant, the winds are generally "upslope," and therefore favorable to precipitation. Also over its southeastern quadrant the wind is moving "upslope" from the Gulf. But over that portion of its southern quadrant lying east of the divide and west of the belt of southeasterly winds from the Gulf is the area embracing eastern New Mexico and extreme western Texas, where the wind is blowing "downslope," and therefore is unfavorable to precipitation. For this reason, a storm area passing eastward approximately along the northern border of the State causes general precipitation over all the area under its influence, with the exception of this "dry belt."

The accompanying chart (fig. 1, XLIV–72) shows an ideal wind circulation around one of these depressions. The precipitation areas of many LOWS show remarkable conformity to this theoretical one.

A large number of the southern LOWS are southern centers of low troughs. But even in depressions that are regularly formed, there seems to be a strong tendency of the Gulf winds to blow in from the southeast, often blowing in a straight line, or even recurving slightly to the north, when the low center is located as shown on the theoretical circulation. On the chart presented this tendency is emphasized to show the wind-shift line, which normally marks the western limit of precipitation.

The distribution of precipitation around a depression is illustrated in the four composite maps presented in figures 2, 3, 4, 5. These were constructed from the average data for a number of LOWS in approximately the same positions, and show the average pressure, wind direction, and precipitation frequency for LOWS cen-

[5] *See* their work "Centres d'action de l'atmosphère."
[6] Svenska Hydrografisk-Biologiska Kommissionens Skrifter, V.
[1] Accompanied by Charts XLIV–72 to XLIV–76. Figures 1 to 9.